

EVALUATION OF MOSFETS AND IGBTs FOR PULSED POWER APPLICATIONS*

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Abstract

Single solid-state devices or arrays of solid-state devices are being incorporated into many pulsed power applications as a means of generating fast, high-power, high repetition-rate pulses and ultimately replacing hard tubes and thyratrons. While vendors' data sheets provide a starting point for selecting solid-state devices, most data sheets do not have sufficient information to determine performance in a pulsed application. To obtain this relevant information, MOSFET's and IGBT's from a number of vendors have been tested to determine rise times, fall times and current handling capabilities. The emphasis is on the evaluation of devices that can perform in the range of 100ns pulse widths and the test devices must be capable of switching 1000 volts or greater at a pulsed current of at least 25 amperes. Additionally, some devices were retested with a series magnetic switch to evaluate the effects on switching parameters and specifically rise times. All devices were evaluated under identical conditions and the complete test results are presented.

I. INTRODUCTION

The Beam Research program at Lawrence Livermore National Laboratory has been developing solid-state high voltage adders for induction accelerator applications. The biggest determining factor of the performance of these adders is the series/parallel array of field effect transistors (MOSFETs) and/or insulated gate bipolar transistors (IGBTs) used for the main switching device. Once the parameters are determined for the adder (voltage, current, pulse width, rise and fall times, mechanical constraints, etc.) a device can be chosen that best fits the application. Since the vendors' data sheets for these devices do not always provide sufficient performance information for the narrow pulse widths required (~100ns), the selection process for the optimum device becomes a significant research and testing effort in itself. Samples of MOSFETs and IGBTs received from multiple vendors, such as APT, IXYS, and Intersil, are tested for their performance. The data for all devices are compiled and compared and a candidate that best meets the optimal parameters is

chosen. This paper describes the test setup, procedures and results for devices that have a rating of 1000 volts or greater for a pulsed current of at least 25 amperes.

II. TEST SET-UP

When testing devices for rise and fall times, the total loop inductance in the circuit/test fixture significantly affects the device turn-on time and to determine the true speed of the device, the inductance of the circuit/fixtures needs to be as low as physically possible. In order to achieve this a test fixture was designed and fabricated for the specific purpose of testing these devices. Traces on the pc boards were made very wide and kept as close to one another as possible. Also, the capacitor bank was made up of several capacitors in parallel. The load boards were also made with wide, close traces and many resistors in parallel.

The test circuit has a capacitor bank with enough stored energy to sustain a desired pulse width without excessive droop for a wide range of load currents. The test circuit also has interchangeable resistive loads so the current through the device can be varied.

The gate drive circuit used in this test fixture was developed for a previous application and was designed specifically to turn these devices on and off very quickly. It is tightly coupled to the test device to minimize inductance.

MOSFETs and IGBTs come in a variety of case sizes and the ones that best fit our application are the TO-247 and TO-264 packages. The test fixture was designed to accommodate either. Figure 1. shows the test circuit.

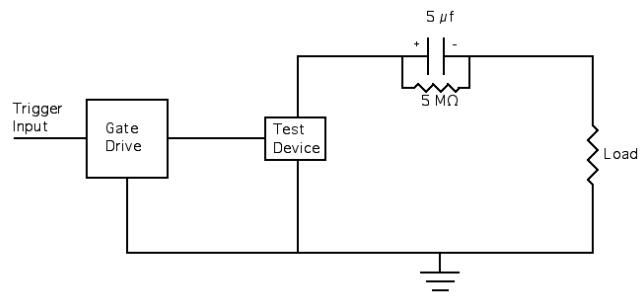


Figure 1. Test circuit

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III. INITIAL CIRCUIT TESTING

The first device tested in the fixture was an APT1001RBVR (1000V, 10A) MOSFET that was used in other applications and had been well characterized. Preliminary testing was at 600 volts into a 34Ω (17.65A) load with a 100ns pulse width.

The testing of the circuit showed the fixture to be functioning properly but the turn-off time (26ns) of the test device (Figure 2.) was slightly slower than the 17ns that had been documented for this device in other applications.

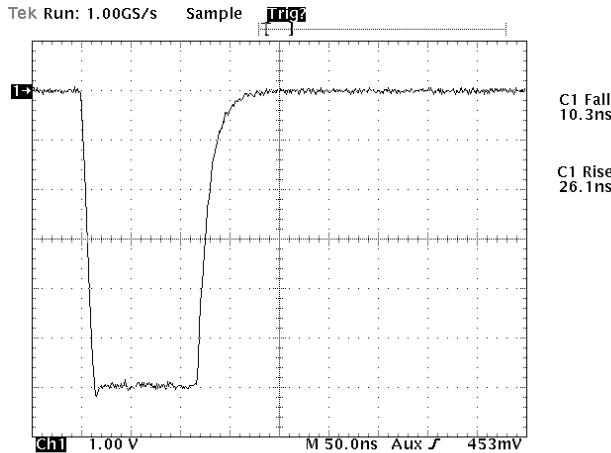


Figure 2. Load voltage for APT1001RBVR (600 volts, 34Ω , 100ns). Note: Since this is a negative pulse the oscilloscope measures the turn-on time as the “fall”.

IV. MODIFYING THE CIRCUIT

Experiments showed that adding inductance to the circuit in parallel with the load resistor (Figure 4.) helped to speed up the turn-off time. It was decided to add the amount of inductance to the fixture that the device would normally see in the real application of an adder modulator (i.e. the magnetization current of the adder transformer primary winding). Measurements made on our existing adder showed each device would see approximately $33\mu\text{H}$ of inductance. A $33\mu\text{H}$ air core toroid was wound and added to the fixture and the load voltage was measured. Notice in Figure 3. the modification has decreased the turn-off time to 17ns but there is now an inductive overshoot at the end of the pulse. This overshoot adds to the voltage already appearing across the device. Also, for fast repetition pulses, such as a burst mode, the voltage should return to zero volts before the device turns on again for the next pulse.

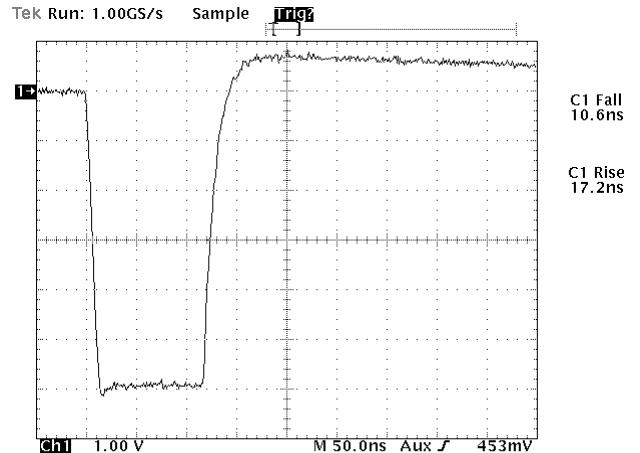


Figure 3. Load voltage with $33\mu\text{H}$ inductor.

A snubber circuit was added to the fixture to clamp this overshoot while maintaining the fast turn-off. With these circuit modifications the test fixture is a very close representation of a modulator type environment. Figure 4. shows the modified circuit.

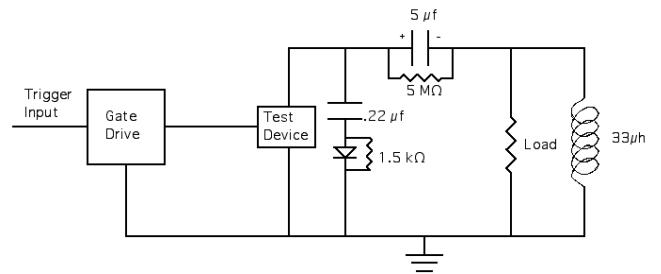


Figure 4. Modified circuit of test fixture.

Figure 5. shows the load voltage of the modified circuit. Notice there is very little overshoot and the turn-off time was slowed only slightly.

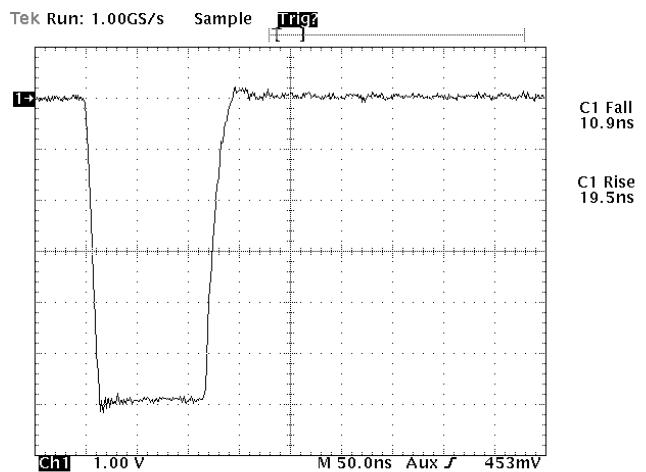


Figure 5. Load voltage with $33\mu\text{H}$ inductor and snubber added to the circuit.

V. TEST PROCEDURE

In order to compare the performance of many devices the testing procedure and parameters were kept consistent throughout the experiment. The capacitor bank was charged to 1000 volts and the trigger input to the gate drive was set for a 100ns pulse width. The load voltage was measured with a 100:1 voltage probe and the rise and fall times (10%-90%) were calculated by the oscilloscope. This data was recorded for each load value: 34Ω, 25.5Ω, 20.3Ω, 16.8Ω, 14.7Ω, 12.5Ω, 10.2Ω, 8.5Ω, 5.7Ω, 2.7Ω. As the current increased, the voltage drop across the device increased. The current through the device was calculated by measuring the load voltage and dividing it by the value of load resistance. Typical measurements at 1000V on the DC capacitor are shown in Figure 6. Note the variation in voltage drop across the test device and also the effect on the rise and fall times. For the data collected here the “peak measured current” was arbitrarily chosen to be the current through the device when a 50 volt drop is measured across the device. Most of the IGBTs were too slow to be properly tested at 100ns pulse widths and were retested with pulse widths of 500ns or greater.

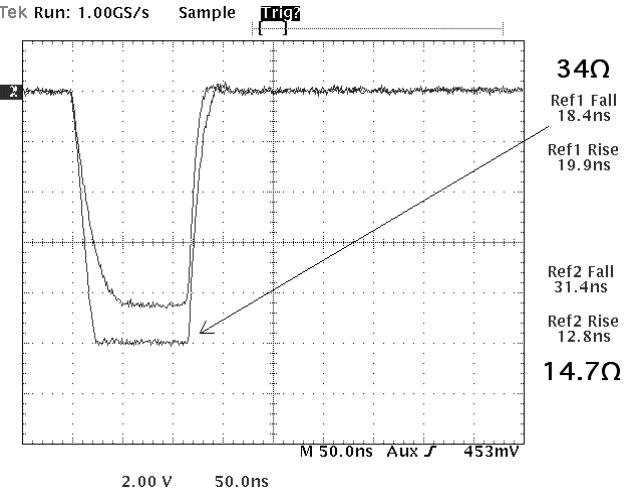


Figure 6. Overlay of 34Ω and 14.7Ω loads.

Once the voltage, current and rise and fall times of the device were recorded for each load value the next device was installed in the fixture and tested using the same exact conditions and procedures.

VI. TEST RESULTS

The data for all devices was compiled (Table 1.) and performances compared.

Table 1. Performance of tested devices.

Device	Rated Voltage	Rated Pulsed Current	Peak Measured Current	Turn-On Time	Turn-Off Time	Type
APT1001RBLC	1000V	44A	44A	19ns	13ns	MOSFET
APT1001RBVR	1000V	44A	47A	20ns	13ns	MOSFET
APT10086BLC	1000V	52A	56A	25ns	12ns	MOSFET
APT10050LVR	1000V	84A	76A	34ns	13ns	MOSFET
APT10053LNR	1000V	80A	85A	43ns	43ns	MOSFET
APT10040LVR	1000V	100A	95A	44ns	40ns	MOSFET
APT1201R5BVR	1200V	40A	40A	19ns	13ns	MOSFET
APT12080LVR	1200V	64A	65A	26ns	12ns	MOSFET
HGTG27N120BN	1200V	216A	56A	80ns	20ns	IGBT
IXBH40N160	1600V	40A	37A	60ns	20ns	IGBT
*IXGH45N120	1200V	180A	361A	226ns	681ns	IGBT
*IXSH35N120A	1200V	140A	172A	234ns	52ns	IGBT
*APT50GF120B2R	1200V	160A	167A	415ns	90ns	IGBT
*APT20GF120BDR	1200V	64A	60A	132ns	23ns	IGBT
*IXSH35N140A	1400V	140A	173A	217ns	257ns	IGBT
*APT15GF170BDR	1700V	50A	48A	121ns	19ns	IGBT
*IXBH42N170	1700V	180A	169A	133ns	61ns	IGBT

* Tested at 500ns or greater pulse widths to obtain peak current.

VII. MAGNETIC SWITCH ASSIST

Several of the IGBTs that were tested had turn-on times that were too slow for our application. In an attempt to speed up these devices a magnetic switch was installed in series with the load (Figure 7).

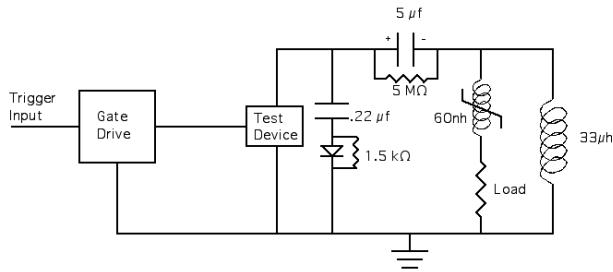


Figure 7. Circuit with magnetic switch.

The magnetic switch delays the current through the test device, giving the device time to fully turn on before conducting. Although the same magnetic switch was used for all of the devices and not optimized for each, it did have a substantial effect on the turn-on times for several of them. Figure 8. shows the load voltage for an IGBT (HGTG27N120BN) with and without magnetic switch assist. This device had a turn-on time that was too slow to reach its peak current in 100ns. Therefore, it was tested at a 500ns pulse width and reached a peak current of 98A. Table 2. shows turn-on times for several IGBTs that were improved using magnetic switch assist.

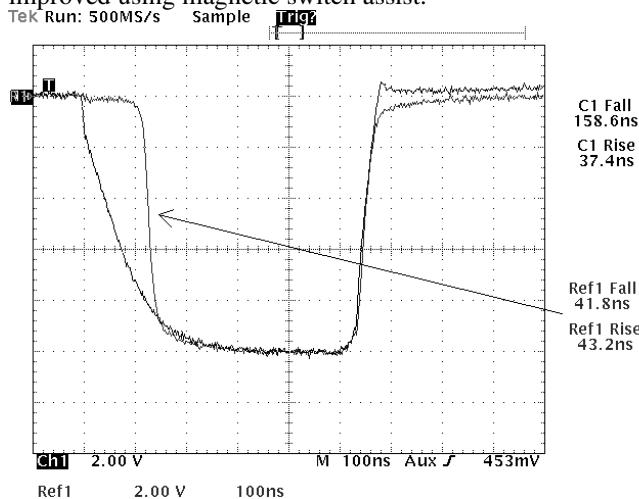


Figure 8. Ref 1 with magnetic switch, Ch 1 without.

Table 2. Turn-on times with and without magnetic switch

Device	With	Without	Current
IXBH40N160	43ns	60ns	38A
APT15GF170BR	57ns	121ns	48A
APT20GF120BDR	40ns	132ns	68A
HGTG27N120BN	41ns	158ns	98A
APT50GF120B2R	43ns	285ns	150A

VIII. SUMMARY

Many MOSFETs and IGBTs were obtained from several vendors and tested for their performance in narrow pulse width conditions for the purpose of selecting a device that would best meet the strict parameters of a pulse power application. A circuit was designed and a low inductance test fixture was fabricated for this specific test effort. Voltage, current, turn-on times and turn-off times were recorded for each test device and the data was compiled and compared.

The MOSFETs typically had faster rise and fall times but were lower current devices than the IGBTs. Although the IGBTs met the current handling parameters for our application their rise and fall times were much too slow. Many of them had their turn-on times greatly improved using a magnetic switch in series with the load. Although this helped with many (not all) of the IGBTs, the magnetic switch did not improve the turn-on times of the MOSFETs. In fact some MOSFETs had their turn-on performances slowed by the added inductance of the magnetic switch.

IX. REFERENCES

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